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CO_2 mitigation strategy through geothermal energy, Saudi Arabia

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ABSTRACT

Saudi Arabia is generating 194.4 billion kWh of electricity through 500,000 barrels of oil. With the demand of electricity growing at 7.5% annually, the country may need 8.3 million barrels oil per day by 2020. This is going to put the country as the leader among the top CO_2 emitting countries by 2020 with emissions peaking at 750 Gg of CO_2 from the current 400,000 Gg. This is not a healthy sign for the country's GDP. The country can easily mitigate this problem by using the available wet and EGS (enhanced geothermal system) geothermal systems. 13 million Gg of CO_2 can be mitigated by utilizing its geothermal energy sources for desalination plants along the western coastal region. Another 900 Gg can be mitigated by adopting GHP technology for space cooling and heating. Change in energy policy, solving tariff related issue and adopting CDM through geothermal energy sources, Saudi Arabia can mitigate CO_2 emissions and still maintain its supremacy in the world.

Contents

1. Introduction

Geothermal energy is a clean source of energy with minimum emission of CO_2 compared to other fossil fuel energy resources. The present electricity generation through geothermal source is touching over 11,000 MWe [1] and several countries have realized the benefits of geothermal and developing all the available high and low enthalpy geothermal resources for power generation as well as for direct application. On an average geothermal power plants emit 0.893 kg CO_2/MWh while oil fired power plants emits 817 kg CO_2/MWh and gas based power plants emit 193 kg CO_2/MWh [2]. Saudi Arabia has reasonable wet geothermal and abundant EGS resources that are yet to be utilized. Due to the availability of large volume of

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oil and gas reserves, these resources have not drawn the attention it deserves. By implementing clean development mechanism (CDM) through geothermal, the country can mitigate CO_2 emissions and exploit the oil and gas resources for a longer period of time and gain carbon credits as well. The advantage of harnessing this green energy is the main focus of this paper.

2. Energy demand and CO_2 emission

Saudi Arabia, occupying the bulk of the Arabian Peninsula, is the third largest Arab country and the largest Middle East country. Saudi Arabia has an estimated population of 28 million [3] spread over an area of about 2.2 million sq. km. The country has the world's largest oil reserves and main revenue comes from 90% export of oil. Saudi Arabia's per capita energy consumption is 7400 kWh with the demand growing at the rate of 7.5% per year. According to the 2009 World Bank statistics, the country has generated 194.4 billion kWh of electricity (96 billion kWh from oil and 99 billion kWh from gas, [3]). This is generated by burning 500,000 barrels of oil [3]. In summer 900,000 barrels a day is needed to meet the demand. The current consumption of oil is 3.4 million barrels day. According to the projections, the country may need 8.3 million barrels per day of oil by 2020 with 3 million oil reserved for power sector. By the year 2020 the country's power generation capacity will reach 77 GWe from the current 44.5 GWe (Fig. 1) with current population growing at the rate of 6% [3]. Building sector consumes nearly 80% of the electricity produced for cooling purpose. In addition 17 million kWh is needed to provide per capita water requirement at the current demand of 235 L/day. Thus oil and gas play a crucial role in the economy and GDP of Saudi Arabia which is a part of MENA countries (Middle East North Africa). The MENA countries, having a large share in oil production compared to other countries, have a crucial role to play in controlling the CO_2 emission and mitigate global climate change. The CO_2 emission in Saudi Arabia increased from 139,000 Gg in 1999 to 400,000 Gg in 2011 and is projected to touch 750 Gg by 2020 (Fig. 2 [4]). By the year 2020, with a 6% growth in population and 16.14 Gg of CO_2 emissions per capita, the total CO_2 in 2020 will be 756×10^6 Gg. In the case of utility services, CO_2 from electricity and heat production is 26×10^6 Gg and CO_2 from residential, commercial and public service is 900 Gg. Due to severe shortage of fresh water supply, Saudi Arabia has to rely on desalination process to support drinking water demand. The CO_2 emission from desalination plants is 13 billion kg if oil is used and 3 billion kg if gas is used. However, there is large scope for Saudi Arabia to mitigate CO_2 emissions and adopt clean development mechanism (CDM) by using geothermal energy as a source mix. In this paper we document the available wet geothermal source as well as EGS (Enhanced Geothermal System) and suggest methods to reduce CO_2 emission from fossil fuel based energy sources.

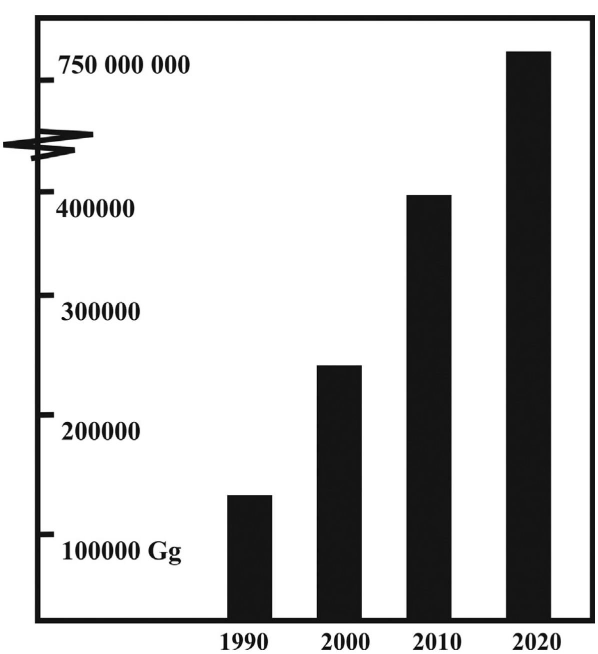

Fig. 1. CO_2 emission per year.

3. Geology and tectonic fabric of Saudi Arabia shield

3.1. *Evolution of volcanic centres "The Harrats"*

The genesis of the geothermal provinces along the western Arabian shield is coeval with the geological and tectonic evolution of the shield. The drifting of the Arabian shield was initiated by a plume below the Afar as shown in Fig. 3a. Prior to the onset of the Plume related Red Sea rift and continental drift, island arc tectonics dominated the western Arabian shield between 830 and 630 Ma [6]. The later tectonic style followed the Precambrian regional structure. The plume activated drift, that was initiated at about 31 Ma, changed the arc tectonics along the coast, that have evolved from island arc tectonics formed through a series of subduction episodes, to compressional regime and gave rise to thick folded metamorphic crust [7,8,6,9]. During the changeover of tectonic style, from subduction to rift, underplating of a more basic crust (6.8–7.8 km/s, gabbroic, [6,10], Fig. 5) occurred below the Precambrian crust that became the main source for syn-rift and post-rift basic and acidic volcanism and intrusion of felsic magmas. Initial plume related volcanism is represented by older Harrats (Harrats Uwaynd, Hadan, Sirat, Harairah and Ishara) aligned parallel to the arc subduction geometry (Fig. 4) and spread over a period from 31 to 15 Ma, while the younger, post rift magmatism and plutonism extended between 10 Ma to Recent [11]. The rock types that dominate these older Harrats are picrites, Ankaramites, alkali olivine basalts [12]. The pre-rift arc system was very complex and evolved between microplates, the junction of which later developed into ophiolite zones i.e. the Bir umq, Halaib-Yanbu and Nabitah suture zones [13,14,8] that divided the entire shield in to several terrains. The lithological assemblages that dominate the suture zones include ophiolites, primitive volcanics, calc-alkaline intrusive. The geochemical signatures of these rocks represent primitive mantle composition [6]. The opening if the Red Sea started near the Gulf of Aden and propagated towards north. The Red Sea spreading axis followed the Precambrian tectonic fabric represented by the Najd fault system with major extension axis aligned NE-SW (Fig. 3b). The syn-rift and post rift volcanic activity is represented by basic dikes swarms parallel to the Red Sea axis, volcanic centres (Fig. 6) and post tectonic intrusion of a large number of felsic rocks. The dike intrusion activity spread over a period of 5 Ma extending between 25 and 20 Ma [15,11,5]. The dike swarms are regional, extending thousands of kilometres parallel to the eastern margin of the Red Sea coast, and some of them were feeders to the flows that accompanied the event. The regional and depth extent of these dikes are very prominent on regional gravity and aeromagnetic profiles [6,10]. The volume of the younger volcanic flows represented by the Harrats Uwaynd, Khaybar, Rahat, Kishb, Nawassif and Al Birk is much larger compared to the lavas erupted due to the plume activity (Fig. 7). The area now occupied by the volcanic flows is about 90,000 km^2 [12]. Volcanic activity along the western shield is very active and magmatic activity as has been reported from Harrat Lunayyir recently in 2009. Seismic analyses of 2009

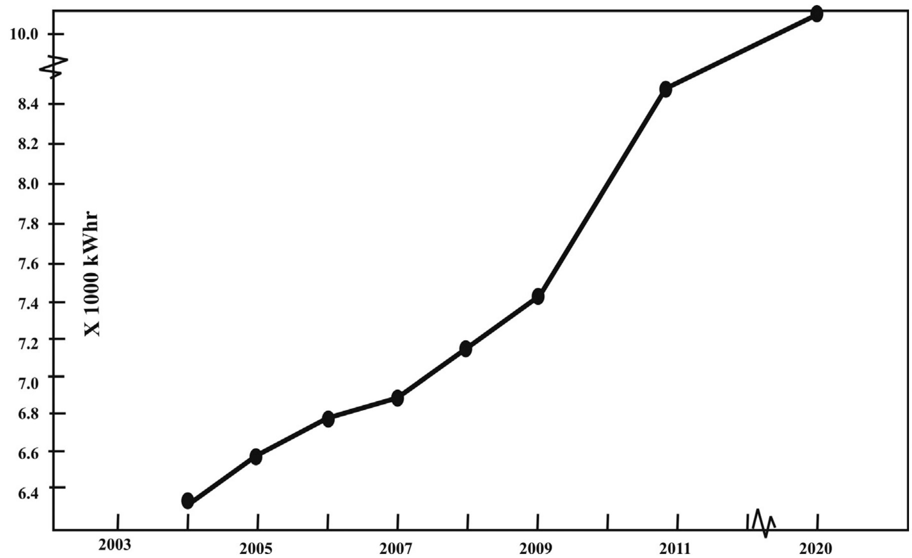

Fig. 2. Annual electricity consumption.

earthquakes have demonstrated intrusion of dike at a depth of 8 km below Harrat Lunnayyir [16–18]. Further, fumarole activity is reported from Harrats Khayber [12]. The fumarolic activity indicates active magma chamber at shallower depth and also supports the presence of steam heated aquifers at some depth. Steam heated aquifers occurs where the lave flows over, or insulate paleo-channels [12]. Historical eruptions of the Harrats Lunayyir (1000 AD), Ithnayn (1800 AD), Al Madinah, (1256 AD), Khayber (650 AD), Rahah (500 AD) and Jabal Yar (1810 AD) suggest that these volcanoes are dormant and may revive its activity in future as the Red Sea rift axis is very dynamic with its rate of spreading varying from 1.6 to 3 cm/y [12,19]. These Harrats with a geothermal gradient of 90 °C/km [12], like the east African rift zones, are store house of geothermal energy. The volcanic centres in East Africa (east African rift including Ethiopia and Kenya), Djibouti (Lake Assal and Lake Abhe) are coeval to the Harrats of western Arabian shield (Fig. 3) and have similar geothermal systems operating. While Kenya is generating nearly 500 MWe from its volcanic field, Tendaho started establishing 5 MWe geothermal power plant in Tendaho. Assessment of geothermal potential in Lake Assal and Lake Abhe has been made [20]. The Olkaria geothermal field has been assessed for its production of power against the area of volcanic flow by Bodvarsson et al. [21]. Based on extensive field assessment, wells drilled (production and injection) and power produced over the last 6 to 7 years, these authors have concluded that in a volcanic setting like Olkaria, 1 km^2 of flows with high heat flow and geothermal gradient should yield, on a conservative side, about 173×10^6 kWh. Similar analogy has been adopted for the Lake Abhe geothermal fields [22]. In the case of Saudi Arabia, assuming that 10% energy is extractable, the Harrats that occupy about 90,000 km^2, should be able to generate 200×10^6 kWh of electric power.

3.2. Post tectonic plutonism

The western Saudi Arabian shied, encompasses about 770,000 km^2 of area, encloses, besides the volcanic rocks that were described above, large volume of plutonic rocks (Fig. 7). Nearly 55% of the rocks that outcrop in the shield area are plutonic rocks. These plutonic rocks were evolved in four stages. Between 900 and 630 Ma, plutonism was dominated by intermediate plutonic rocks such as diorite, quartz diorite, tonalite and trondhjemite. During the periods 680–630 and 660–610 Ma the magmatic style changed from arc to collision type, resulting in the evolution of rocks of granitic composition (granodiorite, monzogranite, syenogranite, and alkali felspar granite). The last stage of evolution that occurred between 610 and 510 Ma, resulted in the widespread intrusion of post-orogenic, intracratonic, evolved, peraluminous to peralkaline alkali-feldspar granites. Nearly 37% of the plutonic rocks that are exposed in the shield are granites [23]. These last stage granitic rocks became focus of intense investigation because these rocks are enriched in several elements of economic importance including radioactive elements like uranium, thorium and potassium [24,10,23,25]. The late stage granitic rocks are termed as high heat generating granites because the heat generated by these rocks due to radioactive decay of uranium, thorium and potassium is anomalously high relative to normal granites. The significance of such rocks as clean energy source is discussed in the following sections.

The Precambrian structural elements i.e. Najd fault system, were periodically activated during the entire four stage plutonic magmatism, as indicated by the alignment of earthquake foci along the fault zone [26], and continued its activity during the initiation of the Red Sea rifting. Thus the Najd fault system (Fig. 3c and d) and the associated paleo arc suture zones [23] became loci of hydrothermal mineral deposits [6,27–29,13]. Besides the heavy metals and transitional metals, the hydrothermal deposits associated with Najd fault systems and paleo suture zones include kasolite (uranyle mineral), uranium rich thorite, uraniferous fluoride-complexes and pyrochlore [30]. These minerals in the granites and associated pegmatites gave rise to high temperature geothermal systems along the western Arabian shield.

4. Renewable energy sources

Solar PV, wind and geothermal energy sources are available in the country and can be utilized to mitigate CO_2 emissions and mitigate global climate change problems and implement clean development mechanism (CDM). As long as oil and gas sources are available, Saudi Arabia will not have the problem with energy security. But oil and gas resource are not renewable and over a course few years the reservoir will become dry. By using energy mix, the country can extend the life of the oil and gas resources and adopt environmentally sustainable development. The renewable are independent and are not susceptible to price fluctuations due to international demand. Compared to wind and solar PV,

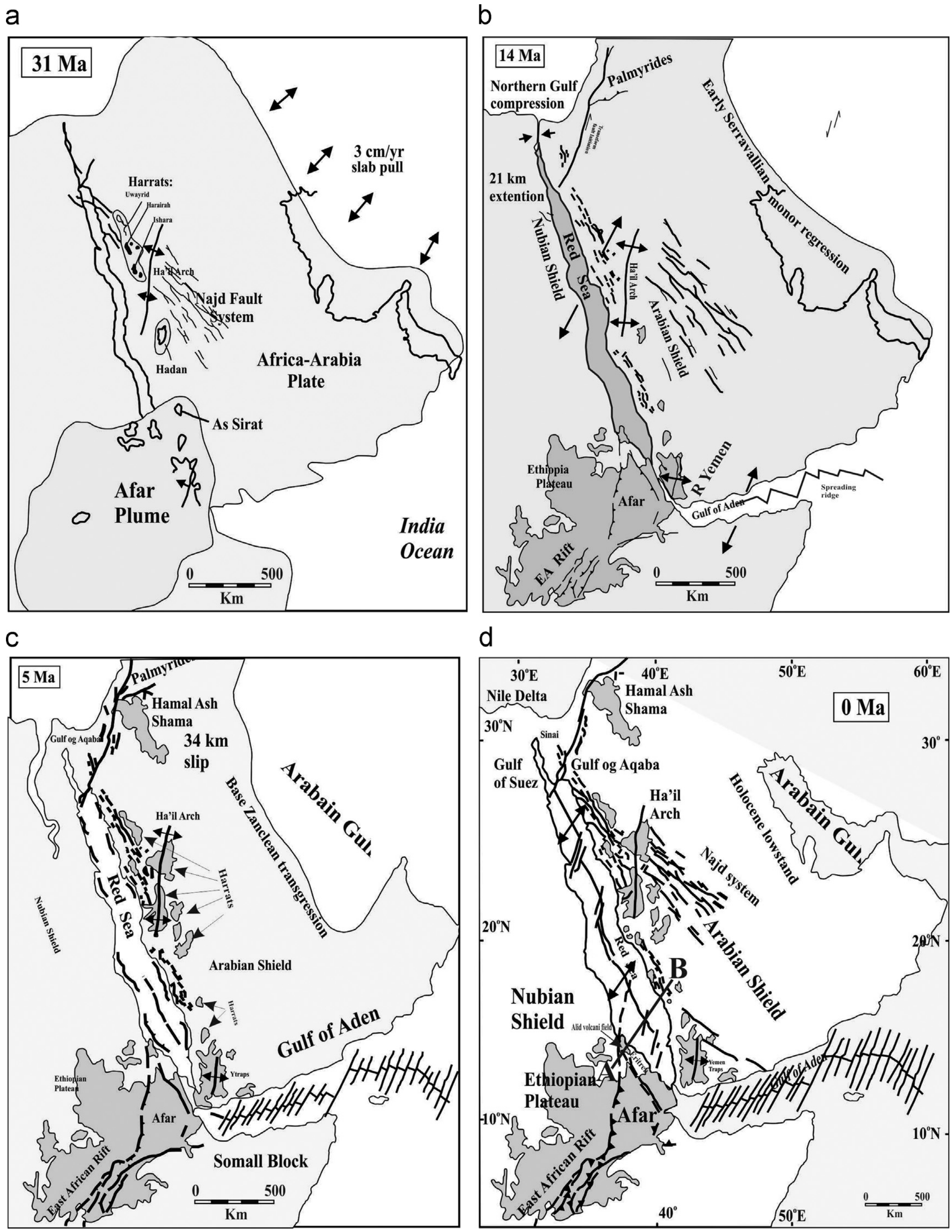

Fig. 3. (a) Evolution of the western Arabian shield was initiated by a plume at the junction of Afar. Initial volcanism over the Arabian plate started around 31 Ma. As Sirat volcano evolved over the plume. Initial stress field during this period was oriented NW-SE (shown as short arrows) which gave rise to post plume Harrats. Precambrian tectonic fabric represented by Najd faults was activated during the opening of the Red Sea. (b) At 14 Ma Red Sea rifting was initiated rotating the Arabian plate anticlockwise direction. (c) At 5 Ma the younger Harrats were well developed with large outpouring of basaltic lavas over the Arabian landmass. (d) Red Sea rifting was active by this period. The faults that were formed during the entire stages of evolution channelized sea water into the landmass. These fluids together with the heat from the volcanoes gave rise to geothermal systems along the coast. Present day active rifting is evident from historical volcanic activity and seismic activity along the western coast and intrusion of dikes below Harrat Lunayyir (see text for further details) Modified after [5].

geothermal energy can provide based load electricity supply and the power plants on an average work at 97% efficient level and these systems can operate for over 20 to 30 years. The land requirement for geothermal poer plants is minimum compared to other renewables. For example, land required for 1 MWe geothermal power plant is 1.2 acre while wind and solar require 65 to 12 acre of land respectively, to generate same quantity of electrical power.

5. Geothermal systems of Saudi Arabia

The western continental margin of Saudi Arabia hosts greater than 50 thermal spring emergences with issuing temperatures varying from 31 to 79 °C with flow rate of 5 to 20 L/m [31–33]. These springs can be classified in to two groups: (1) those associated with Harrats and (2) those associated with high heat

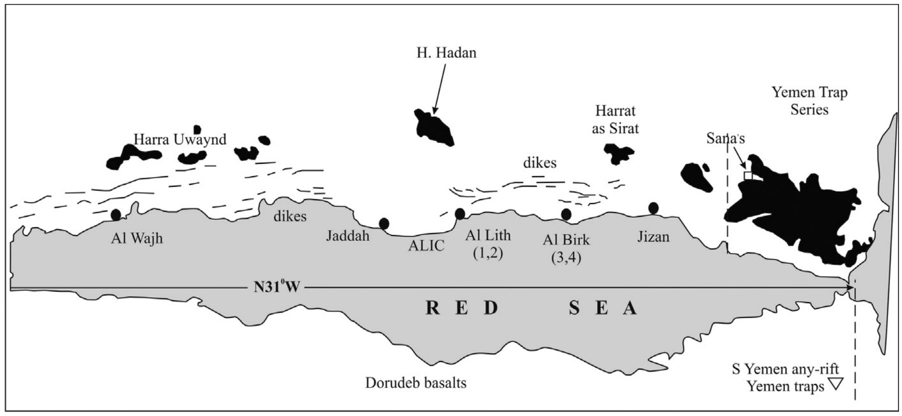

Fig. 4. Plume activated older Harrats followed accurate style followed by the intrusion of dikes swarms. The pattern of the dikes swarms shows the orientation of the initial fault system that developed due to the plume activity. Large volume of lava evolved near the plume (present day Yemen). Volcanism migrated towards north as rifting progressed north (modified after [5]).

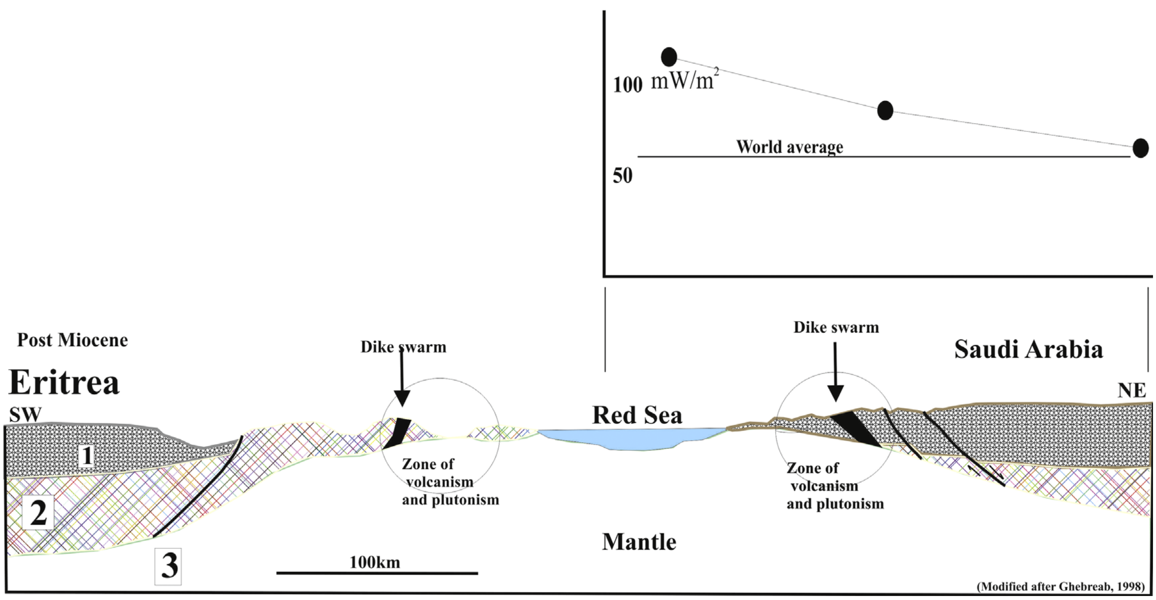

Fig. 5. Schematic subsurface profile across section A-B in Fig. 3. At the end of the evolution stage (Fig. 3d), Red Sea rift was well established with continued activity. Plume related volcanism appears to have resulted in underplating of high density material along the western Arabian shield (gabbroic) forming basic lithosphere that subsequently gave rise to felsic intrusives and basic dikes. Presence of shallow mantle and crustal magma chambers gave rise to high geothermal gradient and elevated heat flow values along the coast. The zone of plutonism and volcanism lies just below the lithosphere-asthenosphere boundary.

generating granites. The location of geothermal sites is shown in Fig. 7. Those systems that are associated with the Harrats are high temperature fumaroles described in Section 4 above. These steam pools are generated due to escape of steam from rising magma, or degassing in the magma chamber or due to boiling aquifers (paleo channels) that are buried by the volcanic flows in all Harrats. These geothermal systems are similar to those operating in Ethiopia, Lake Abhe in Djibouti and Kenya rift valley where the source of heat for the circulating fluids is the magma that lies within the crustal chambers. These thermal springs are fault controlled with regional faults running parallel to the coast and are aligned with the major Najd fault system of the Arabian Shield. The geothermal systems are coeval to the evolution of the Harrats and the post tectonic magmatic and volcanic (dike swarms) along the coast and continue to operate due to the prevailing high heat flow and conduction of heat from the paleo suture zones, and existence of mantle at shallow level (~20 km, [34–36,31]) The heat flow values across the western margin of the shield is shown in Fig. 5. The value is much above the normal heat flow value reported from shield regions (50 mW/m^2). While the normal heat flow values over shield region is 50 mW/m^2, the heat flow value recorded over the margin of Al Lith (Fig. 7) is >80 mW/m^2 [10].

5.1. Geochemistry of the thermal waters

The range of chemical constituents in the thermal waters is shown in Table 1. Groundwater occurring in basalt flows are generally of Ca–HCO_3 type while the water that occur in granites is of Na–HCO_3 type. The chemistry is controlled by the minerals phases that are predominant in such rocks. The Ca/Na ratio in basalts is greater than one while in granitic rocks, it is below unity [37,38]. The geothermal waters from the west coast of Saudi Arabia are enriched in chloride (Fig. 8, Table 1) unlike the groundwater that occurs in granite aquifers.

High chloride content in the thermal waters indicates long water rock interaction in the geothermal reservoirs at elevated temperatures [39,40]. Based on the tritium values in the geothermal waters,

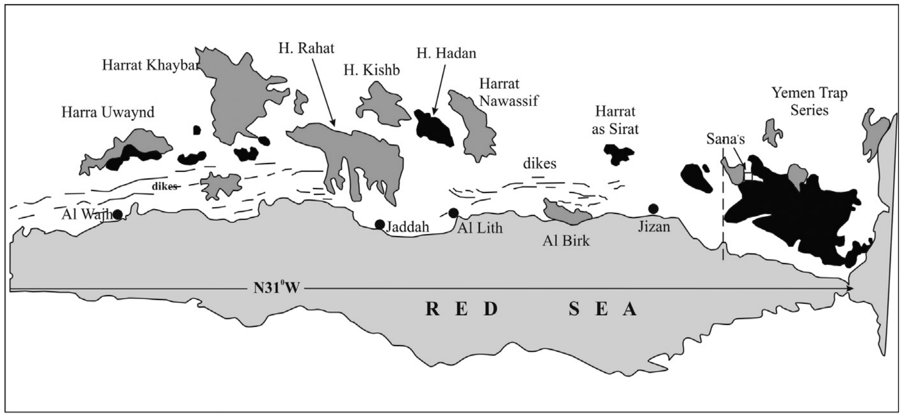

Fig. 6. Syn-rift and post rift dike and volcanic centres. Post plume volcanic activity resulted in outpouring of large volumes of basaltic lavas from several centres along the coast giving rise to younger Harrats. These volcanic field occupy nearly 90,000 sq.km and several paleo drainage basins aquifers. Due to the out pouring of lavas water evaporated from these paleo channels together with steam from the volcanoes gave rise to fumaroles in several Harrats and thus giving rise to vast geothermal systems along the coast (modified after [5]).

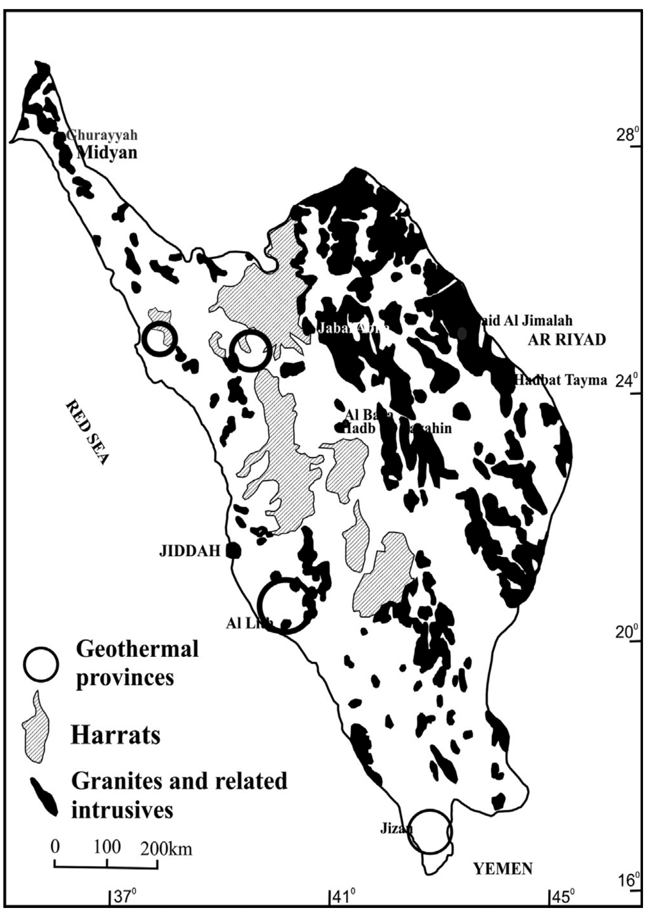

Fig. 7. Map showing the fields of Harrats, felsic intrusives and geothermal provinces (modified after [12,23]).

the residence time of the geothermal waters of Saudi Arabia varies from 500 to 100 years [33,41]. Oxygen and hydrogen isotope signature in the thermal waters show "oxygen shift" indicating exchange of oxygen between rock and ascending waters at temperatures greater than 220 °C [41,42]. This gives support to the reservoir temperatures estimated from cation geothermometers (Table 1) that varies from 130 to 280 °C. The geochemical data clearly demonstrates the presence of a high temperature geothermal systems long the west coast of Saudi Arabia.

The thermal waters are enriched in boron (370–508 ppm, [41]) suggesting their circulation through peraluminous and peralkaline granites (see Section 4, Fig. 7) that contain $>1\%$ boron [41]. Boron evolves as an end phase volatile during the crystallization of granites and gets trapped in tourmaline [43] that occur commonly as an accessory mineral in the granitic rocks. Large crystals of tourmaline with high content of boron crystallize when granitic melts intrude the ultramafic zones along the ophiolite zones described in Section 4. Tourmaline veins also occur as veins in the granitic rocks [13,44–48].

6. High heat generating granites

Almost all the post tectonic granitic rocks that accounts to 77% of the plutonic rocks, described in Section 4 above, contain anomalously high concentration of uranium, thorium and potassium. In fact such high concentration raised concern among the builders who were using granites as ornamental stones and construction material [50–52]. The peralkaline granite plutons of the Arabian shield, numbering seventy, are the largest number ever recorded in the world [53–57]. The surface area occupied by these granites, extending from Midyan in the north to Jizan in the south (Fig. 7) is about 161,467 km^2 [57]. As described in Section 4, uranium content in kasolite found in these granites is 46% (UO_3, [58]) that makes the granite an economically important source for uranium. These granite generate high temperatures due to disintegration of radioactive elements and the heat generated by these granites is shown given in Table 2.

The heat generated by these granites is several folds greater than the heat generated by the normal granites ($\sim 5\ \mu W/m^3$, [59]). 1 km^3 of such granite can support generation of 79×10^6 kW h of electricity for a period of 30 years [60]. Generating power from such granites is now well established as has been demonstrated by France in Soultz and by Australia in Cooper Basin. Assuming that 2% of the total potential heat is extractable from the granites of Saudi Arabia through enhanced geothermal system concept (EGS), a conservative amount of 120×10^6 TW h electricity can be generated [57,61]. By considering the volume of high heat generating granites present the western margin of Saudi Arabia, and the prevailing NE-SW compressional stress acting on these granites, these rocks are excellent source for initiating EGS projects for power generation. In fact, according to the MIT report on EGS, [62], the high heat generating granites are going to be the main source of energy in the 21st Century in USA, anticipated to generate 100,000 MWe of baseload electricity by 2050.

Table 1
Range of chemical constituents in thermal springs from Saudi Arabia.

	Location	Temp (°C)	pH	Na	K	Ca	Mg	Cl	HCO_3	SO_4	RTC
8#	Al Lith	44–79	7.7–7.9	134–621	10–111	94–601	60–70	270–2059	12–107	193–600	130–280
4#	Jizan	55–75	7.1–7.3	850–1025	27–30	252–549	16–56	671–1934	142–200	330–470	123–257

RTC: Reservoir temperature in °C; 8# number of samples; Data *source*:[31,33,41,49].

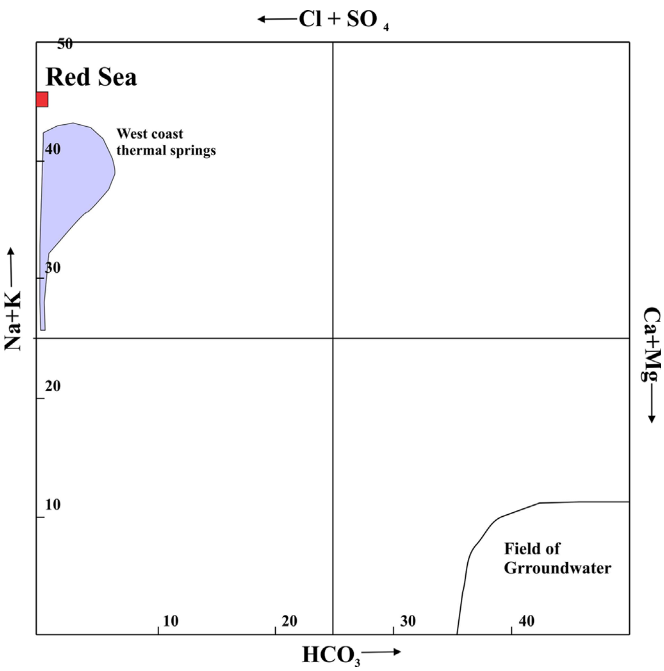

Fig. 8. Chemical characteristics of geothermal waters, West coast of Saudi Arabia.

Table 2
U, Th and K content and heat production in granites of western Saudi Arabia [57].

Location	U (ppm)	Th (ppm)	K (%)	μW/m³
Baid al Jimalah	13.3	35.2	3.87	6.2
Hadb ad Dayahin	13.7	28	2.4	5.6
HadbatTayma	14.6	25	3.9	5.8
JabalKhinzir	30	8	3.5	8.5
JabalSaqrah	26	49	4	10.4
Ghurayyah 4	104	625	3.12	70.2
Ghurayyah 5	88	160	3.17	33.9
Ghurayyah 6	363	590	1.4	134.2

Table 3
Countries using Geothermal energy [63] and CO_2 savings.

Country	1	1A	Country	2	2A
USA	16,603	13.56	**China**	20,932	17.1
Philippines	10,311	8.42	**USA**	15,710	12.8
Indonesia	9,600	7.84	**Sweden**	12,585	10.28
Mexico	7,047	5.75	**Turkey**	10,247	8.37
Italy	5,520	4.5	**Japan**	7,139	5.83
Iceland	4,597	3.75	**Norway**	7,000	5.72
New Zealand	4,055	3.31	**Iceland**	6,768	5.53
Japan	3,064	2.5	**France**	3,592	2.93
Kenya	1,430	1.16	**Germany**	1,546	1.26
El Salvador	1,422	1.16	**Netherlands**	2,972	2.43
Costa Rica	1,131	0.92	**Italy**	2,762	2.26
Turkey	490	0.4	**Hungary**	2,713	2.22
Papua New Guinea	450	0.36	**New Zealand**	2,654	2.17
Russia	441	0.36	**Canada**	2,465	2.01
Nicaragua	310	0.22	**Finland**	2,325	1.90

1—Electricity GW h/y, 2—Direct Use GW h/y, 1A and 2A—CO_2 savings in billion kg.

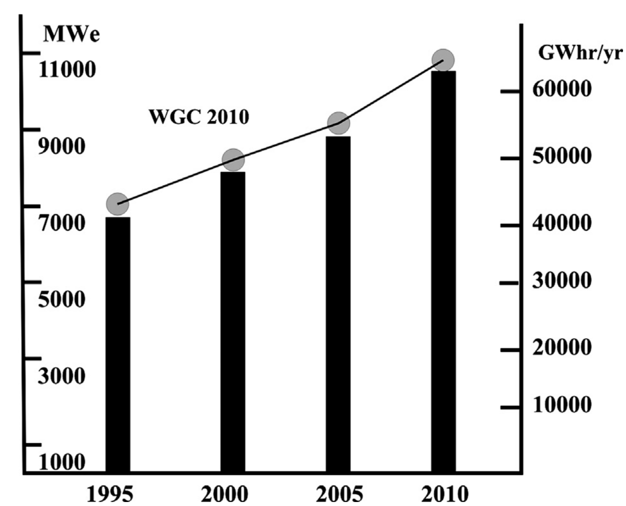

Fig. 9. Growth curve of world geothermal power generation.

7. Geothermal power: World status

The World Geothermal Congress, an affiliated body to the International Geothermal Association compiles country update data every five years. The top fifteen countries that are saving CO_2 emissions through geothermal source is given in Table 3 [63]. In 1990s very few countries were generating electricity from geothermal and the first power generator was installed in Larderello, in Italy in 1904. As on date nearly 24 countries are generating electricity from geothermal source. Small island countries like Papua New Guinea are utilizing geothermal power to reduce oil imports and mitigate carbon dioxide emission. Between 2005 and 2010 there is an increase of 50% installed power from geothermal source worldwide. A detailed country wide electricity generation from geothermal source is given by Bertani [63]. As shown in Fig. 9, there is a linear growth of 200 MWe/year generation across the countries [63], with simultaneous reduction in CO_2 emission. Oil based power plants emit 817 kg/MWh of CO_2 while coal based power plants emit 953 kg/MWh of CO_2 [2]. Thus the reduction in CO_2 emission by geothermal power plants in the year 2010 (including all the 78 countries) is of the order of 54 to 63 billion kg.

As for as direct application is concern, nearly 78 countries are utilizing geothermal power for direct application like space heating and cooling, dehydration, greenhouse cultivation and aquaculture. Between 2005 and 2010, there is an increase of 72% of direct use through geothermal. At the end of the year 2010, 48,493 MWt is used for the above applications. Category wise, 62% is used for space heating and cooling through ground source heat pumps and 5% for green house application. Energy saved through direct application is 250 million barrels of equivalent oil annually preventing 33 million tonnes of carbon and 107 million tonnes of CO_2 being released [64].

The data provided above is related to hydrothermal or wet geothermal systems where heat is brought to the surface through

a carrier medium i.e. water that penetrates into deeper parts of the earth crust. Now, as described in Section 6 above and documented by the MIT report [62] and demonstrated by France (Soultz EGS project in France, [65], and Cooper Basin Hot dry rock project in Australia, [66,67]), high heat generating granites are the future focus of energy source in the world [62]. Now instead of circulating water that is causing inherent glitches due to water rock interaction and super-saturation of circulating fluids, carbon dioxide is being circulated to extract heat from these granites for electrical power generation [67–69]. At present the levalized cost of power generated from EGS source varies between AU cents 10–12/kW h [67]. If the carbon earnings and costs related to the damage caused to the environment through CO_2 emissions from conventional sources of energy (Coal and Oil and gas) are factored into the levalized costs, EGS source will be the best option to bridge the gap between demand and supply of electric power and to minimize the damage to the environment and the atmosphere.

8. Cost of power

The cost of renewable energy technologies shows considerable variation between the countries and different locations within a country. This is mainly due to the tax structure, technologies used etc. For example, some of the non-OECD (Organization for Economic Cooperation and Development) countries are still using old technologies for generation of power and are not adopting clean development mechanism for mitigating CO_2 emissions. Because of the tax structure, capital cost variations becomes an issue in generalizing the cost of production of electric power across countries. In majority of the countries, decarbonisation of the power sector is still in its infancy. In the case of certain energy sources, like nuclear, risks involved in disposing high level waste are variable. Cost subsidies in a majority of the countries with respect to the source is an issue in arriving at a cost structure. For example, at 5% and 10% subsidy, the cost of nuclear generated electric power costs 29 US$/ US$/MWh and 42 US$/MWh in Korea while in Hungary it is 82 US$/kWh and 132 US$/MWh respectively. Similar is the status with respect to the cost of coal based power plants. Cost is controlled by the location of the power plant. If the plant is located near the coal mines, it is less expensive and if the plant is away from the source, transportation gets included into the cost [70]. Such variation are inherent with respect to electric power generated from other sources as well.

However, taking into account all such factors, the U.S Energy Information Administration [70] published levalized costs for unit of electric power generated from different sources. This gives a summary measure of the broad competiveness of different energy sources involved in generating electric power in US. Table 4 gives the levalized cost (at 2011 US$ value) for the generating sources of energy that will be entering production in the year 2018. These values act as guidelines (that are otherwise not available) to project costs for renewables and evaluate them against the savings through reduced CO_2 emissions.

From Table 4 it is quite clear that electricity generated through geothermal source is very competitive and with technologies maturing (design of high efficient heat exchangers and drilling rigs) the cost of unit power will further decline. Perhaps the levalized unit cost of power from ESG source will also further decline (see Section 7) making all the countries, especially those depending on imported fossil fuels, energy independent.

9. Clean development mechanism and energy policy

As described above Saudi Arabia's CO_2 emission is expected to touch 750 billion Gg by the 2020 nd per capita emission is expected to be 756 million Gg. Besides this, 13 billion CO_2 is being emitted from desalination plants along the western coast of the country where most of the desalination plants are located. The current consumption of electric power to meet the water demand discussed above is about 17×10^6 . The country can save about 13 million Gg of CO_2 by using geothermal energy for desalination process. Saudi Arabia, as described above, being a ware house of high heat generating granites, can adopt clean development mechanism within a short period of time by harnessing heat from these granites for power generation and save billions of barrels of oil for future generation. Besides reducing CO_2 emissions to a large extent, the country can earn carbon credits and become economically further strong. Further when oil and exploitation is conserved, it will keep the country's economy strong for centuries and continue to control the future world market. Energy source mix to support its ever growing power demand is an ideal CDM for the country that will make the country more energy independent. With so many benefits and clean energy sources in hand why Saudi Arabia is not able utilize this opportunity for the benefit of its population? The answer lies in the country's energy policy. According to M.F. Coviello, member of the UN Economic Commission for Latin Americas, one of the basic requirement for strengthening and regulating a country's renewable resources is a strong political will on the part of the decision makers [71]. This is valid in the case of geothermal resources. In countries where development of geothermal resources is part of political commitment, there is a tremendous development of this resource. This has been proved by countries like Italy, USA, Indonesia and Philippines. It has been demonstrated internationally that existence of a national geothermal authority is inevitable for regulating exploration and development of such resources. Where ever such regulatory body exists, geothermal energy has seen an upswing [71]. Although it is reported that geothermal energy resource is not being developed due to certain barriers [72], it is a misconception because this study was based on poor statistical sampling data. The real issue seems to be related to tariff for renewables in general. The country has, so far, not paid attention to this issue there by keeping the investors at bay. Sooner or later, these issues will be resolved since the country has already experiencing variable weather pattern and increase in summer air temperature [73] and perhaps forced to take a policy decision related to renewables.

Table 4
U.S average levalized costs (2011 $/MWh) for plants entering production in 2018.

Source	1	2	3	4	5	6
Conventional coal	85	65.7	4.1	29.2	1.2	10
Advanced coal	85	84.4	6.8	30.7	1.2	12.3
Natural Gas						
Combined cycle	87	15.8	1.7	48.4	1.2	6.7
Combustion turbine	30	44.2	2.7	80	3.4	12
Advanced Combustion. Turbine	30	30.4	2.6	68.2	3.4	10.4
Advanced nuclear	90	83.4	11.6	12.3	1.1	10.8
Geothermal	92	76.2	12	0	1.4	8.96
Biomass	83	53.2	14.3	42.3	1.2	11.1
Wind	34	70.3	13.1	0	3.2	8.66
Wind-offshore	37	193.4	22.4	0	5.7	22.1
Solar PV	25	130.4	9.9	0	4	14.4
Solar thermal	20	214.2	41.4	0	5.9	2.61
Hydro	52	78.1	4.1	6.1	2	9.03

1—Capacity factor; 2—Levalized capital cost; 3—Fixed O & M; 4—Variable O & M; 5—Transmission investment; 6—Levalized cost US$c/kWh
Note: (a) Costs are expressed in terms of net AC power available to the grid for the installed capacity. (b) Hydro is assumed to have seasonal storage so that it can be dispatched within a season but overall operations is limited by resources availability by site and season (*Source*: [70]).

10. Conclusions

As on today Saudi Arabia, although has a large geothermal energy potential, this source is not being utilized due to abundant oil and gas reserves. Continued exploitation of fossil fuels will only make the country a major CO_2 emitter in the world. Large emissions of CO_2 will be detrimental to the country's growth and environment as has been documented in a recent study [73]. Temperature rise by 0.7 °C over a period of a decade is a matter of concern for any country. By implementing CDM through geothermal, the country can sustain the oil and gas reserves for a longer period of time in the coming centuries and also mitigate CO_2 emissions to a large extent as described above. For space cooling purpose the country consumes nearly 155 billion kWh of electricity (80% of the electricity generated). This amount together with the amount of electricity spent on desalination can be offset by geothermal power within a short period time. GHP (Ground source Heat Pump) alone can save 900 Gg of CO_2 emissions from residential and commercial public service buildings. Being located along an active rift zone, heat source is not a problem to the entire western shield region. As long as the Red Sea rift is active, Saudi Arabia will have sufficient geothermal energy to support its ever growing demand for electricity and fresh water and maintain a constant GDP growth and enjoy its supremacy in oil production for a longer period of time. It is apparent from the forgone discussions that geothermal energy has large positive impacts on the environment and society compared to the conventional fossil fuels. There are no technical barriers for developing this source for power generation and for direct application. The only barrier is energy policy that the country has to overcome. The Government needs to adopt renewable as a part of its national energy agenda anticipating future demand, depleting oil reserves and climate change. Since the country has vast oil and gas resources, its policy makers are not bothered to work out a tariff structure for the renewable resources. Without a defined tariff structure, the country cannot attract investors to develop this source. The country may be compelled to take this issue seriously considering the change in the weather pattern that the country is experiencing over the past decade. Major oil exploration companies in Saudi Arabia have now realized this lacuna and are keen in adopting energy source mix model to meet future electricity demand thereby reducing domestic consumption of oil and increasing export quantity.

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